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PROCEDURE AND PROGRAM OF THE CALCULATIONS ON TSVM (UBM - DIGITA--ETC(U)
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PROCEDURE AND THE PROGRAM OF THE CALCULATIONS ON TSVM [ЦВМ - DIGITAL COMPUTER] OF TRANSIENT PROCESSES IN LINEAR ELECTRICAL CIRCUITS WITH THE CONCENTRATED PARAMETERS

by

V. V. Il'inichnin, L. A. Korolev, L. S. Levin

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	α		Nu	Ν	ν	
Beta	Β	β			Xi	Ξ	ξ	
Gamma	Γ	γ			Omicron	Ο	ο	
Delta	Δ	δ			Pi	Π	π	
Epsilon	Ε	ε	ϵ		Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ			Sigma	Σ	σ	ς
Eta	Η	η			Tau	Τ	τ	
Theta	Θ	θ	ϑ		Upsilon	Υ	υ	
Iota	Ι	ι			Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ	ϰ	Chi	Χ	χ	
Lambda	Λ	λ			Psi	Ψ	ψ	
Mu	Μ	μ			Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

—

rot	curl
lg	log

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TRANSACTIONS OF VNIIE [ВНИИЭ - ALL-UNION SCIENTIFIC RESEARCH INSTITUTE OF ELECTRIC POWER ENGINEERING]. All-Union scientific research institute the electro-energeticists.

V. V. Il'inichnin, L. A. Korolev, L. S. Levin. Pages 35-45.

Procedure and the program of the calculations on TsVM [ЦВМ - digital computer] of transient processes in linear electrical circuits with the concentrated PARAMET~~RAMI~~ERS.

During the design of electrical systems frequently appears the need for the study of electromagnetic transient processes. A similar need appears also in operational practice for the analysis of the complex forms of damages on power transmissions of high and ultrahigh stress, checking and the selection of equipment, etc. In VNIIE was developed the procedure and were carried out the program of the calculations of transient processes in digital computers (TsVM) in

distributed circuits (concentrated linear reactive cell/elements are replaced by the cuts of long lines) [1. 1]. This work headed by doctor of tech. sciences, by Prof. A. I. Dolginov, under management/manual of whom began to be developed other directions of the calculations of electromagnetic transient processes on TsVM. one of such directions was use TsVM for the calculations of transient currents and voltage/stresses in electrical circuits by the concentrated cell/elements (cell/elements of grid/network with the distributed parameters are represented by the appropriate replacement schemes).

In present article are represented the procedure and the program of the calculations of electromagnetic transient processes on TsVM in electrical circuits with lumped parameters with the use of numerical methods of integration.

Fundamental principles. For the calculation of electromagnetic transient processes on TsVM by the numerical methods of approximative integration must be comprised the system of differential equations in canonical form.

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For the composition of the reference system of differential equations we utilize equations of the junction/unit potentials, which characterize this electrical circuit:

$$gu = I, \quad (1)$$

where

$$u = \begin{Vmatrix} u_1 \\ u_2 \\ \cdot \\ \cdot \\ \cdot \\ u_k \end{Vmatrix}$$ matrix column k of the potentials of the assemblies circuit with respect to the base line assembly, potential of which is accepted equal to zero;

$$I = \begin{Vmatrix} I_1 \\ I_2 \\ I_k \end{Vmatrix}$$ matrix column k of the assigning currents in the assemblies of replacement scheme;

$$g = \begin{Vmatrix} g_{11} - g_{12} \cdot \cdot \cdot - g_{1k} \\ -g_{21} + g_{22} \cdot \cdot \cdot - g_{2k} \\ \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \cdot \\ -g_{k1} - g_{k2} \cdot \cdot \cdot g_{kk} \end{Vmatrix}$$ the square matrix/die of order k its own and vzamnykh conductivities the assemblies of circuit.

If we consider that

$$p \equiv \frac{d}{dt} \text{ и } p^{-1} \equiv \int_0^t ,$$

that resistor/resistance of branch $Z_{\overline{mn}}$ between two assemblies m and n is expressed by the following rating value from p:

$$Z_{\overline{mn}}(p) = pL_{\overline{mn}} + R_{\overline{mn}} + p^{-1}C^{-1}_{\overline{mn}}, \quad (2)$$

where $L_{\overline{mn}}, R_{\overline{mn}}, C^{-1}_{\overline{mn}}$ - are values of inductance, of effective resistance and inverse capacitance/capacity of the cell/elements, connected in series between assemblies m and n.

Respectively elment $g_{mn}(p)$ matrix/die g (p), in line m

confronting and column n, in oshchem form is represented by the expression

$$g_{mn} \approx g_{nm} = \sum \frac{1}{pL_{mn} + R_{mn} + p^{-1}C_{mn}^{-1}},$$

in which the amount of terms it depends on the number of parallel connections between assemblies m and n (m $\neq$ n), and also the number of connections of danogo assembly (m = n) with other k the assemblies of the initial circuit.

From (1) the unknown potentials of assemblies are determined through the known assigning currents i and matrix/die z = g^{-1} their own and mutual impedances of the assemblies of circuit, i.e.,

$$u(p) = Z(p)\,i. \qquad (3)$$

Matrix/die Z (p) is calculated by matrix inversion g (p) and as it will be shown below, it can be represented in the following form:

$$Z(p) = \frac{1}{\Delta(p)} \begin{Vmatrix} a_{11}(p) & a_{12}(p) & \dots & a_{1k}(p) \\ a_{21}(p) & a_{22}(p) & \dots & a_{2k}(p) \\ \dots & \dots & \dots & \dots \\ a_{k1}(p) & a_{k2}(p) & \dots & a_{kk}(p) \end{Vmatrix}. \qquad (4)$$

Cell/element $Z_{mn}(p)$ matrix/die Z (p) - the correct rational fraction, in which and numerator $a_{mn}(p)$ and denominator Δ (p) - polynomials from p:

$$Z_{mn}(p) = \frac{a_{mn}(p)}{\Delta(p)} = \frac{a_0 + a_1 p + a_2 p^2 + \dots}{\Delta_0 + \Delta_1 p + \Delta_2 p^2 + \dots}. \qquad (5)$$

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From (3) ks by account (4) the voltage/stress of any assembly m with respect to base line is equal to:

$$u_m(p) = \sum_{n=1}^{k} \frac{a_{mn}(p)}{\Delta(p)} I_n. \qquad (6)$$

Often larger interest are of not the potentials of assemblies with respect to base line, but the potential difference between assemblies m and j, which it is easy to obtain, replacing in (6) values $a_{mn}(p)$ by the coefficients, equal to a difference in the corresponding coefficients of the numerators of lines m and j of matrix/die Z (p) (4), i.e.,

$$u_{mj}(p) = \sum_{n=1}^{k} \frac{a_{mn}(p) - a_{jn}(p)}{\Delta(p)} I_n. \qquad (7)$$

If current in branch mj with resistor/resistance $Z_{mj}(p)$ is equal to

$$I_{mj}(p) = \frac{u_{mj}(p)}{Z_{\overline{mj}}(p)}, \qquad (8)$$

that for the determination of currents $I_{mj}(p)$ it is possible to use equation (7), after replacing Δ (p) with value Δ' (p), equal to

$$\Delta'(p) = \Delta(p) Z_{\overline{mj}}(p),$$

i.e.

$$I_{mj}(p) = \sum_{n=1}^{k} \frac{a_{mn}(p) - a_{jn}(p)}{\Delta'(p)} I_n. \qquad (9)$$

It must be noted that equations (6), (7), (9) can be written by single pattern;

$$y=\sum_{n=1}^{k}\frac{A(p)}{B(p)}I_n, \qquad (10)$$

where y are unknown value, and A(p) and B(p) are polynomials respectively of order q and s whose coefficients they are calculated from the known (preset) parameters of the initial circuit.

To operating equation (10) corresponds the following differential equation:

$$B_0y+B_1\frac{dy}{dt}+B_2\frac{d^2y}{dt^2}+\cdots+B_s\frac{d^sy}{dt^s}=$$
$$=\sum_{n=1}^{k}\left(A_{0n}I_n+A_{1n}\frac{dI_n}{dt}+A_{2n}\frac{d^2I_n}{dt^2}+\cdots+A_{qn}\frac{d^qI_n}{dt^q}\right). \qquad (11)$$

The solution to differential equation (11) is reduced to the solution of the system of differential first-order equations, which it is not difficult to obtain vvediyem the supplemental equations, which reduce the order of equation (11):

$$\left.\begin{aligned}
&y=y_0;\\
&\frac{dy_0}{dt}=y_1;\\
&\frac{dy_1}{dt}=y_2;\\
&\quad\vdots\\
&\frac{dy_{s-2}}{dt}=y_s;\\
&\frac{dy_s}{dt}=\sum_{n=1}^{k}\Big(A_{0n}I_n+A_{1n}\frac{dI_n}{dt}+A_{2n}\frac{d^2I_n}{dt^2}+\cdots+A_{qn}\frac{d^qI_n}{dt^q}-\\
&\qquad -B_0y_0-B_1y_1-B_2y_2-\ldots-B_{s-1}y_{s-1}\Big)\frac{1}{Bs}.
\end{aligned}\right\} \qquad (12)$$

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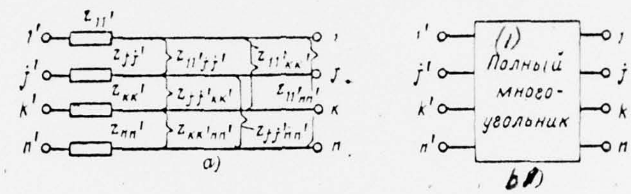
Fig. 1. To the circuit design, which contains the inductively connected cell/elements. a) the group of the ends of chain, connected inductively; b) replacement scheme.

Key: (1). Complete polygon.



On TsVM the solution of obtained system (12) is conducted by the approximation methods of numerical integration.

Give of sootnoveniya make it possible to calculate the transient current and voltage values in schemes at the absence of inductive coupling between cell/elements. The use of a method of junction/unit potentials in the presence of vzaimoinduktivnykh connections is possible with the application/use of a decoupling using the method of complete polygon [1, 2].

In order to use this method for the calculations of transient processes, let us consider that the internal resistance of branch in the initial scheme (Fig. 1A), connected between assemblies j and j' is equal to:

$$Z_{\overline{jj'}}(p) = pL_{\overline{jj'}}.$$

The respectively mutual impedance between the vzaimoinduktivnymi cell/elements kk' and jj' is equal to:

$$Z_{kk'jj'}(p) = pM_{kk'jj'}.$$

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For parameter determination of complete polygon (Fig. 1b) first is constructed the matrix/die $Z_{в э}$ the inductively connected cell/elements

$$Z_{в.з} = \begin{Vmatrix} L_{\overline{11'}} & M_{11'22'} & \ldots & M_{11'nn'} \\ M_{22'11'} & L_{\overline{22'}} & \ldots & M_{22'nn'} \\ \ldots & \ldots & \ldots & \ldots \\ M_{nn'11'} & M_{nn'22'} & \ldots & L_{\overline{nn'}} \end{Vmatrix}.$$

Further is located matrix/die $Y_{вз}$, tc reciprocal matrix $Z_{вз}$, i.e.

$$Y_{вз} = Z_{вз}^{-1}.$$

If we designate matrix element $Y_{вз}$ by Y_{jk}, where j, k = 1, 2, ..., n, then to the reactivity of the branches of complete polygon are equal to:

$$\left.\begin{aligned} Z_{jj'} &= \frac{1}{y_{jj}}; \\ Z_{jk} &= Z_{kj} = -\frac{1}{y_{jk}}; \\ Z_{jk'} &= Z_{jk} = \frac{1}{y_{jk}}. \end{aligned}\right\} \qquad (13)$$

The calculation of currents in the inductive-connected cell/elements of replacement scheme is carried out as follows:

$$I_{вз} = \frac{1}{P} Z_{в.з}^{-1} u_{jj'}, \qquad (14)$$

where $I_{вз}$ is a matrix column of the unknown currents; $u_{jj'}$ - the matrix column of potential differences on the end/leads of branches jj', entering the group of vzaimoinduktivnykh cell/elements.

Substituting in (14) values $u_{jj'}$, calculated on (7), we compose expression for the calculation of currents in the cell/elements, connected by mutual induction, analogous (10), whereupon is form/shaped the system of differential equations.

The calculation of matrix elements z (p). For the calculations

of matrix elements Z (p) is utilized by a logician of the method of the narashchivaiya, utilized for the calculations of the periodichesikh comprising short-circuit currents on TsVM [1. 3, 4]. According to this method complete network is formed by means of the consecutive addition of branches and calculation of matrix/dies $Z_{част}$ for the being obtained sequence of nastichnykh circuits. In each stage of growth is included one branch $\overline{sq}$ replacement scheme between assemblies s and q, resistive $Z_{\overline{sq}}$. Here they can be two cases:

1. The newly included branch $\overline{sq}$ introduces the new assembly q (order of partial matrix/die increases per unit).

2. The newly included branch $\overline{sq}$ does not introduce new assembly (poyadok of partial matrix/die does not increase).

With respect to these two cases the calculation of matrix elements $Z_{част}$ is conducted in different ways.

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In the first case the calculation of the cell/elements of new column and line is carried out on the following of the formulma:

$$\left.\begin{array}{l} \text{a)}\ m \neq q,\ Z_{mq} = Z_{qm} = Z_{sm},\ (m = 1, 2, \ldots, q-1); \\ \text{б)}\ m = q,\ Z_{qq} = Z_{ss} + Z_{\overline{sq}}. \end{array}\right\} \qquad (15)$$

In the special case, when branch $\overline{sq}$ is connected to base line

assembly, i.e., s = 0:

$$\left.\begin{array}{l} \text{a) } m \neq q,\ Z_{mq} = Z_{qm} = Z_{sm} = 0,\ (m = 1, 2, \ldots, q-1); \\ \text{б) } m = q,\ \ Z_{qq} = Z_{\overline{sq}}. \end{array}\right\} \quad (16)$$

In the second case the calculation is conducted into two stages:

1. Are computed the cell/elements of supplemental column and line L:

$$\left.\begin{array}{l} \text{a) } m \neq L,\ Z_{mL} = Z_{Lm} = Z_{ms} - Z_{mq},\ (m = 1, 2, \ldots, L-1); \\ \text{б) } m = L,\ Z_{LL} = Z_{ss} + Z_{qq} - 2Z_{sq} + Z_{\overline{sq}}. \end{array}\right\} \quad (17)$$

In the special case, when branch $\overline{sq}$ is connected to base line assembly, i.e., s = 0,

$$\left.\begin{array}{l} \text{a) } m \neq L,\ Z_{mL} = -Z_{mq} (m = 1, 2, \ldots, L-1); \\ \text{б) } m = L,\ Z_{LL} = Z_{qq} + Z_{\overline{sq}}. \end{array}\right\} \quad (18)$$

2. Are eliminated newly introduced column and line 1, i.e., we obtain the unknown cell/elements of the new partial matrix/die:

$$Z^{\text{н}}_{mn} = Z^{\text{c}}_{mn} - \frac{Z_{mL}\, Z_{Ln}}{Z_{LL}}, \quad (19)$$

where m is a number of line; n - the number of column; L - the designation supplemental the lines also of column; Z^{c}_{mn} - the cell/element of old partial matrix/die (without the account of branch $\overline{sq}$); $Z^{\text{н}}_{mn}$ is a cell/element of new partial matrix/die (taking into account branch $\overline{sq}$).

Taking into account (2) and (5) formula (15) - (18) they will be rewritten as follows:

$$\left.\begin{array}{l} \text{I. } s \neq 0 \\ \quad \text{a) } m \neq q,\ Z_{mq}(p) = Z_{qm}(p) = Z_{ms}(p) = \dfrac{a_{ms}(p)}{\Delta(p)}; \\ \quad \text{б) } m = q,\ \ Z_{qq}(p) = \dfrac{a_{ss}(p) + \Delta(p)\, Z_{\overline{sq}}(p)}{\Delta(p)}; \\ s = 0 \end{array}\right\} \quad (20)$$

$$\left.\begin{array}{l} \text{а) } m \neq q,\ Z_{mq}(p) = Z_{qm}(p) = \dfrac{0}{\Delta(p)}; \\ \text{б) } m = q,\ Z_{qq}(p) = \dfrac{\Delta(p) Z_{\overline{sq}}(p)}{\Delta(p)}; \end{array}\right\} \quad (21)$$

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$$\text{II. } s \neq 0$$

$$\left.\begin{array}{l} \text{а) } m \neq L,\ Z_{mL}(p) = Z_{Lm}(p) = \dfrac{a_{ms}(p) - a_{mq}(p)}{\Delta(p)}; \\ \text{б) } m = L,\ Z_{LL}(p) = \dfrac{a_{ss}(p) + a_{qq}(p) - 2a_{sq}(p) + \Delta(p) Z_{\overline{sq}}(p)}{\Delta(p)}; \end{array}\right\} \quad (22)$$

$$s = 0$$

$$\left.\begin{array}{l} \text{а) } m \neq L,\ Z_{mL}(p) = Z_{Lm}(p) = -\dfrac{a_{mq}(p)}{\Delta(p)}; \\ \text{б) } m = L,\ Z_{LL}(p) = \dfrac{a_{qq}(p) + \Delta(p) Z_{\overline{sq}}(p)}{\Delta(p)}. \end{array}\right\} \quad (23)$$

Thus, the application/use of formulas (20) - (23) is reduced to addition (vychitaiyu) and to the multiplication of polynomials from p.

The basic difficulty in the use of a method of growth conformably to the calculation of transient proyesscv consists of the recalculation of the cell/elements of partial matrix/die $Z_{\text{част}}$ with exception/elimination newly introduced stol'tsa and lines l according to formula (19). At each space of its use of poyadok of numerator and denominator of fractions (5) in limiting case it can increase 2 times. This it is possible to avoid, by converting the algorithm of the exception/elimination of the newly introduced column and line L.

V.sootvetstvii.s (22) in the general case we have:

$$Z_{LL}(p)=\frac{a_{ss}(p)+a_{qq}(p)-2a_{sq}(p)+\Delta^{c}(p)Z_{\overline{sq}}(p)}{\Delta^{c}(p)}=\frac{\Delta^{н}(p)}{\Delta^{c}(p)}, \quad (24)$$

where $\Delta^{c}(p)$ is a polynomial Δ (p) old partial matrix/die (without the account of branch $\overline{sq}$);

$$\Delta^{н}(p)=a_{ss}(p)+a_{qq}(p)-2a_{sq}(p)+\Delta^{c}(p)Z_{\overline{sq}}(p)$$

- polynomial Δ (p) new partial matrix/die (taking into account branch $\overline{sq}$).

Let us rewrite (19) taking into account (24) and (5) as follows:

$$Z^{н}_{mn}(p)=\frac{a^{c}_{mn}(p)}{\Delta^{c}(p)}-\frac{a^{c}_{mL}(p)\,a^{c}_{Ln}(p)}{\Delta^{c}(p)\,\Delta^{н}(p)}=$$
$$=\frac{a^{c}_{mn}(p)\,\Delta^{н}(p)-a^{c}_{mL}(p)\,a^{c}_{Ln}(p)}{\Delta^{c}(p)\,\Delta^{н}(p)}. \quad (25)$$

It is possible to show that the polynomial

$$a(p)=a^{c}_{mn}(p)\,\Delta^{н}(p)-a^{c}_{mL}(p)\,a^{c}_{Ln}(p)$$

has as your divider/denominator polynomial $\Delta^{c}(p)$.

Therefore finally instead of (19) we have:

$$Z^{н}_{mn}(p)=\frac{a^{н}_{mn}(p)}{\Delta^{н}(p)}, \quad (26)$$

where

$$a^{н}_{mn}(p)=\frac{a^{c}_{mn}(p)\,\Delta^{н}(p)-a^{c}_{mL}(p)\,a^{c}_{Ln}(p)}{\Delta^{c}(p)}.$$

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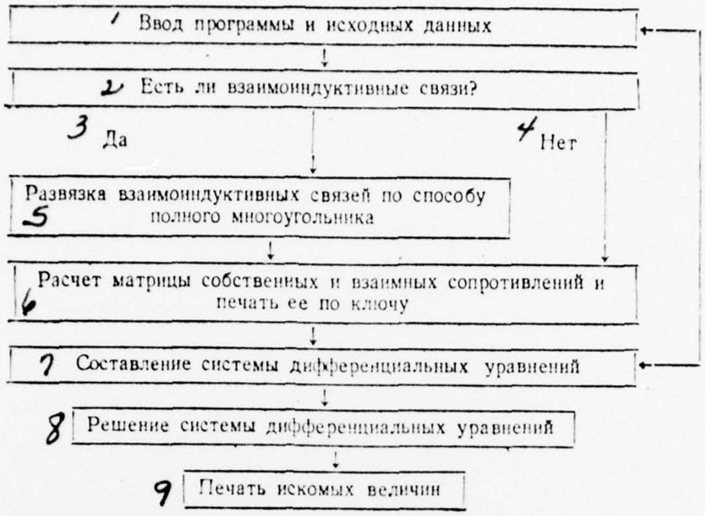
Table 1.



Key: (1). Input routine and the initial data. (2). Are there vzaimoinduktivnye connections? (3). Yes. (4). No. (5). Decoupling of vzaimoinduktivnykh connections using the method of complete polygon. (6). Calculation of the matrix/die of its own and mutual impedances and its printing according to gate. (7). Composition of the system of differential equations. (8). Solution of the system of differential equations. (9). Printing of the unknown values.

Thus, after the switching on of all branches of the circuit from of one and consecutive calculation of the cell/elements of partial matrix/dies finally we will obtain matrix/dies Z (p) in form (4).

The short characteristic of program for TsVM m-220. The initial data for the calculations of transient processes on TsVM are the component values of the substitutions, which include coefficients of L, R, C^{-1} the operating resistor/resistances of the branches of scheme, the coefficients of mutual inductance of network elements and the coefficients, which characterize value and the form of the assigning currents in assemblies. In this case the determination of the unknown values is carried out by the zero initial conditions and the presence of the assigning currents under each assembly of the initial circuit, which take the following form:

$$i_m = A_{1m} \sin(\omega_0 t + \varphi_m) + A_{2m} e^{-\alpha_m t},$$

where $A_{1m}, A_{2m}, \omega_0, \varphi_m, \alpha_m$ are constant coefficients.

For the notation of these data are assigned special places after preliminary coding the assemblies of circuit by the numbers of natural series. After the introduction into working storage TsVM of the indicated initial data and data on the character of the unknown information the calculations of transient process occur automatically.

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The developed program (Table 1) consists of three basic building

blocks: a) the block/module/unit of the replacement of vzaimoinduktivnykh network elements by equivalent replacement scheme;

b) the assembly of the calculation of the values of the coefficients of the matrix elements of its own and mutual operating resistor/resistances;

c) the assembly of composition and solution of the system of the differential equations of the unknown values.

The assembly of the replacement of vzaimoinduktivnykh network elements is designed for five groups of the cell/elements, which have mutual induction. Each such group can into its cchered" contain five cell/elements, connected inductively. Since during the calculations of transient processes, especially in the secondary circuits, can be encountered the more complex forms of inductive coupling, in program is provided the possibility of an increase in the maximum order of the matrix/dies $Z_{из}$, which characterize each such group, because of a decrease in the amount of groups of the cell/elements, connected it is inductive.

After the decoupling of vzaimoinduktivnykh connections the program transfer/converts to the construction of the matrix/die of the operating its own and mutual impedances of replacement scheme and the calculation of the coefficients with operator's different degrees p. Program is designed for the schemes, which contain to 40 assemblies

and 80 branches with the maximum degree of the polynomials of rational-fractional functions (5), equal to twelve. On those which were calculated elementammatritsy Z (p) and the initial information are form/shaped the necessary systems of differential equations for the determination of the unknown values, which are solved by runge - Kutta's method the 4th order. Is simultanecusly feasible the calculation to 15 unknown values.

Cenclusion/derivations.

1. The development of this program showed that the proposed procedure can be successfully used for the calculations of electromagnetic transient processes in complex linear electrical circuits with lumped parameters on TSVM with the automation of all stages of the calculation.

2. The fundamental positions of the develcped algorithm make it possible to propagate it to electrical circuits with the large degree cf differential equation, circuit, which contain nonlinear cell/elements.

Application/appendix.

An example of the calculaticn cf transient process. Let us examine the calculation of transient current during triphase korkotkom closing/shorting on line 500 kV. The network cf primary network is

given in Fig. 2a. Triphase short circuit occurred at the end/lead of the L3P 500 kV, by length 300 km, which is located under voltage/stress from two assemblies 500 kV, each of which consists of three hydraulic generators and transformer group. In the calculation were accepted the following parameters of instrumentation.

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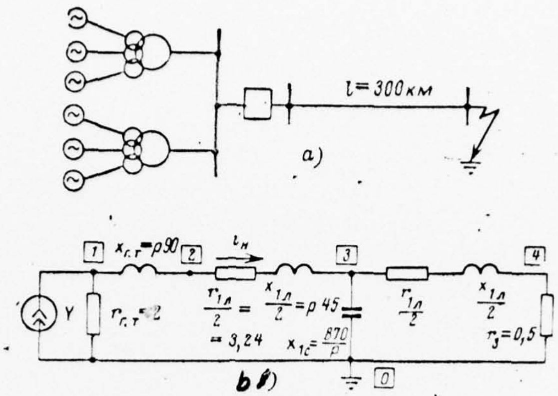

Fig. 2. To the calculation of transient process during triphase short circuit on line 500 kV. a) the scheme of grid/network; b) replacement scheme.

Table. 2.

1 Обозначение ветвей	2 Сопротивление ветвей		
	p^{-1}	p^{0}	p^{1}
01	0	2	0
12	0	0	90
23	0	3,24	45
03	870	0	0
34	0	3,24	45
04	0	0,5	0

Key: (1). Designation of branches. (2). Resistor/resistance of branches.

Generator: $W_н = 135\,000$ kVA, $U_н = 13\,800$ in, $x''_d = 0{,}135$.

The phase of the transformer group: $W_н = 135\,000$ kVA, $U_н = \frac{525\,000}{\sqrt{3}} / 13\,800$ in, $U_к = 13{,}5\%$. lep 500 kV: ℓ = 300 km, r_1 = 0.0216 Ω/km, x_1 = 0.3 Ω/km, $y_{01} = 3{,}87 \cdot 10^{-6}$ S/km.

Figure 2b depicts the calculated replacement scheme, in which $x_{г.т}$ and $r_{г.т}$ - the equivalent inductive and ohmic resistance of both assemblies and $r_з$ - the earth resistance of the duct of substation. Approximately in the calculation it was accepted: $r_{г.т} = 2$ ohm, $r_з = 0{,}5$ ohm. Value emf of all generators was set/assumed by identical, equal e = 360•10, sine τ (τ - time in radians).

For the calculation on TsVM, the assemblies of replacement scheme must be numbered. The version of this numbering is shown in Fig. 1b. V.SOOTVETSTVII.S by the selected numbering in TsVM will be brought in the resistor/resistances of branches in the following form.

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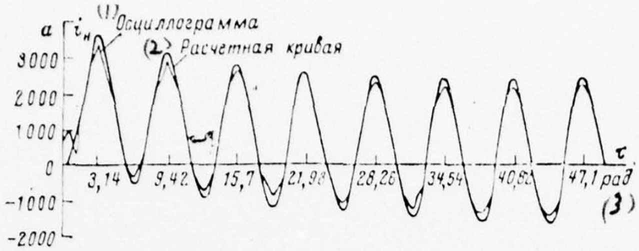

Fig. 8. Calculated and experimental curves of short-circuit current.

Key: (1). Oscillogram. (2). Calculated curve. (3). is glad.

Into information for assembly 1 must be also carried the amplitude and the initial phase of source of current I = 18 010³ sine t ($I_m = 180 \times 10^3$, $\varphi_u = 0$), , and also the value of angular frequency (ω_0 = 1).

Figure 3 shows the calculated curve of short-circuit current at the beginning of line i_u (calculation was carried out by zero initial conditions). For checking the correctness of the obtained result there is given the oscillogram of the secondary current of current transformers, established/installed on this line.

Into conclusion it is possible to note the satisfactory agreement of the calculated and ostsillogrammnoy curves.

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